DTU Library

Ultrasound backscatter from free-swimming fish at 1 MHz for fish identification

Pham, An Hoai; Lundgren, Bo; Stage, Bjarne; Jensen, Jørgen Arendt

Published in:
Proceedings of IEEE International Ultrasonics Symposium 2012

Link to article, DOI:
10.1109/ULTSYM.2012.0369

Publication date:
2012

Document Version
Early version, also known as pre-print

Paper presented at the IEEE International Ultrasonics Symposium, Dresden, Germany, 2012.

Ultrasound backscatter from free-swimming fish at 1 MHz for fish identification

An Hoai Pham, Bo Lundgren, Bjarne Stage, and Jørgen Arendt Jensen

National Institute of Aquatic Resources, Jægersborg Alle 1, 2920 Charlottenlund, Denmark,

and

Center for Fast Ultrasound Imaging,
Biomedical Engineering group, Department of Electrical Engineering, Bldg. 349, DK-2800 Kgs. Lyngby, Denmark,

Technical University of Denmark

To be published in Proceedings of IEEE International Ultrasonics Symposium, Dresden, Germany, 2012.

Ultrasound backscatter from free-swimming fish at 1 MHz for fish identification

An Hoai Pham[1,2], Bo Lundgren[1], Bjarne Stage[1], and Jørgen Arendt Jensen[2]

[1]National Institute of Aquatic Resources, Technical University of Denmark, Jægersborg Alle 1, 2920 Charlottenlund, Denmark
[2]Center for Fast Ultrasound Imaging, Dept. of Elec. Eng. Build. 349, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark

***Abstract*—In the frequency range well below 1 MHz, the swimbladder is often considered the most important part for acoustic fish detection. In this work a portable system was developed to not only detect but also try to identify free-swimming fish. It has been used to measure the ultrasound backscatter at 1 MHz from fish. The system consists of a Reson TC3210 1 MHz single-element transducer, a dual-frequency, multi-beam Blueview P900-2250 sonar, and three Oregon ATC9K cameras. The Reson transducer is connected to an Olympus pulser-receiver monitored by a portable computer through a Picoscope 4226 PC oscilloscope. *Ex-situ* experiments were performed at the NorthSea Oceanarium in Hirtshals, Denmark. The positions, orientations, and lengths of fish were estimated by three dimensional image analysis, taking the measured acoustic distance into account, while species were identified manually. These experiments indicate that at 1 MHz the surface areas (also fins and tail) of the fish can give echoes that are much stronger (up to 3 times) than the swimbladder can, therefore important for identification of fish.**

I. Introduction

This study was performed to investigate ultrasound backscatter from free-swimming fish for investigating fish species discrimination. This would be useful in resource management as well as in commercial fishing. Many groups have researched on ultrasound backscatter from fish with different approaches. In some experiments, fish were immobilized, anesthetized and tied to a fixture as in [1]–[3]. Single element transducers were used to get the target strength from different orientations of the fish. In other experiments, a net was used to limit an area where fish swam free such as in [4]. In addition to single element transducers, cameras were used in a stereo configuration to estimate orientations of fish. Drawbacks of these previous approaches were that the fixture or net interfered with the backscatter signals from the fish and that the net limited the mobility of the fish. Other groups have performed experiments on free-swimming fish without a net to avoid this drawback as in [5], [6]. All of those experiments followed the target strength approach and were performed in the frequency range well below 1 MHz except the work of Jaffe and Roberts [2]. Recently new approaches to use transducers in the MHz frequency range and wider bandwidths have been applied. Many groups have used multi-beam sonars, such as a dual-frequency identification sonar to identify fish species as in [7], [8]. The device gives a two dimensional ultrasound image for each ping and the orientation and the position of the fish can be derived from the images.

One possible approach to identify fish species is to build libraries of reference range profiles of fish as it is done in some radar systems used to identify aircraft [9]. The objective of this work is to develop a single-element transducer system to obtain range profiles of fish. Ultrasound backscatter of the fish is investigated from the range profiles to find a possibility for fish identification.

II. Materials and methods

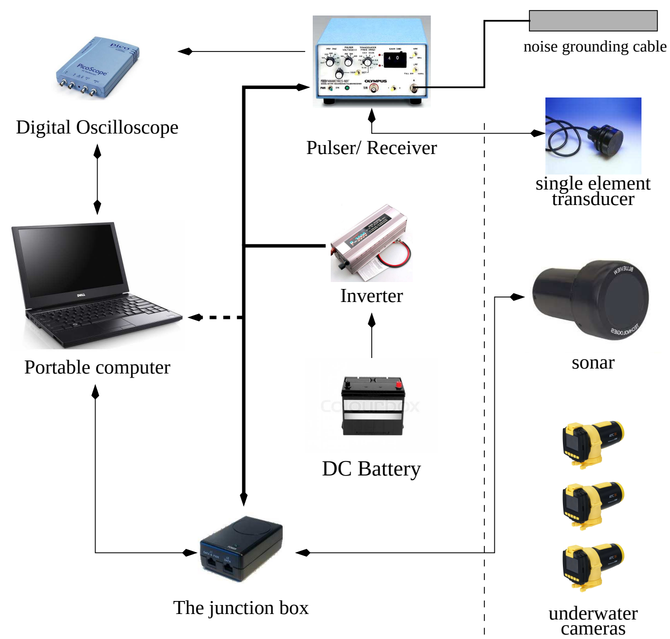

Fig. 1. (Color online) Block diagram of the system. The front-end system is on the left-hand side of the dotted-line.

A system was designed to be portable and can be used for *ex-situ* as well as *in-situ* experiments. The block diagram of the system is presented in Fig. 1. The front-end system consists of a Reson TC3210 1 MHz single element transducer with a bandwidth of 300 kHz, diameter of 2.54 cm, beam divergence angle of 4.5°, a Blueview P900-2250 dual-frequency multi-beam sonar, where only 900 kHz was used, and three Oregon ATC9K underwater cameras, where a resolution of 1280 × 720 pixels was used, all mounted on a fixture. The acoustic devices are connected by cables to the back-end, but the cameras operate independently. There are a battery and a secure digital card in each camera. The back-end consists of a Dell Latitude E4300 portable computer (PC), a Picoscope 4226 digital oscilloscope, where a sampling frequency of 7.813

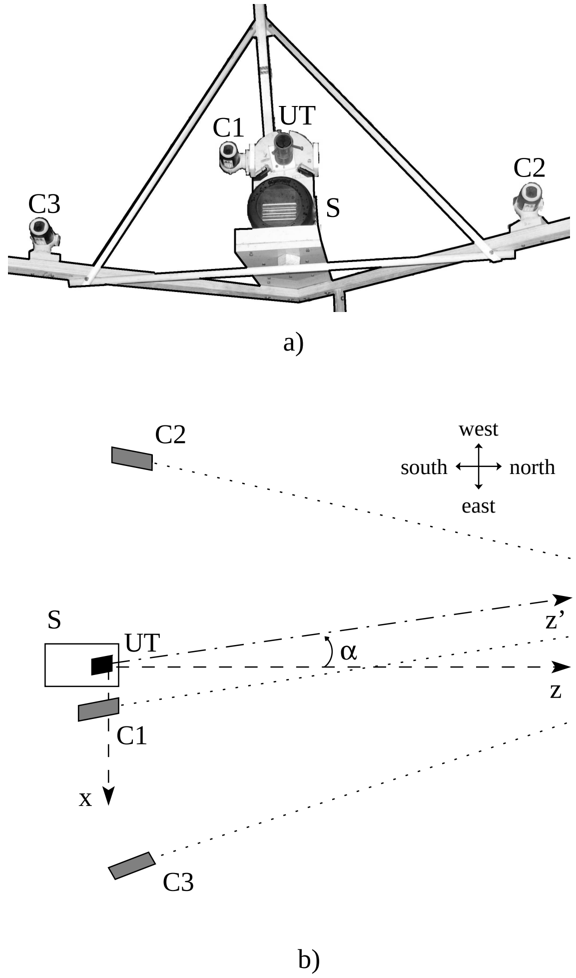

Fig. 2. Setup of the front-end system. C1, C2, and C3 are three identical cameras. UT is the single element transducer. S is the multi-beam sonar. The angle between UT beam and the center beam of S is α. Front-view of the front-end (a). Diagram of the front-end seen from the top (b).

MHz was used, an Olympus pulser-receiver 5077PR, where a pulse repetition frequency of 100 Hz was used, a Proviewer junction box that delivers power over Ethernet to the sonar, a 12V battery, and a power inverter (12 VDC to 220 VAC) that supplies the pulser-receiver and the junction box. The pulser-receiver is used to ping (send the transmit pulse to the transducer), receive and amplify echo signals from the Reson transducer. The received signals are digitized and transferred to the PC using the Picoscope. The Olympus pulser-receiver is grounded to the water with a thick copper cable to reduce the ground loop noise in the received signals from the Reson transducer. The junction box transfers the control signals from the PC to the sonar as well as the sonar data back to the PC. The PC runs on its own battery, but the dotted-line from the inverter to the PC indicates that power can be provided to the PC if necessary.

The configuration of the front-end system is presented in Fig. 2. Fish positions are defined in a coordinate system with an x-axis parallel to the line between cameras C2 and C3, and with xz-plane parallel to the plane of the figure. The center of the aperture of the single-element transducer is used as the origin of the coordinate system. Positive z is away from the transducer and positive y is downwards. The multi-beam sonar is placed below the single-element transducer with its beam plane parallel to the zx-plane. The single-element transducer is directed, so that the center line forms an angle $\alpha = 8.5°$ with the center line of the multi-beam sonar, because the center part of the sonar image is not well-defined. An advantage is also that interfering signals from the sonar are reduced. The optical axis of camera C1 is directed as close as possible parallel to the transducer beam. The distances C1C2 = 64.5 cm, C1C3 = 43.2 cm, and C2C3 = 99 cm are measured between the centers of the camera lenses.

III. Results

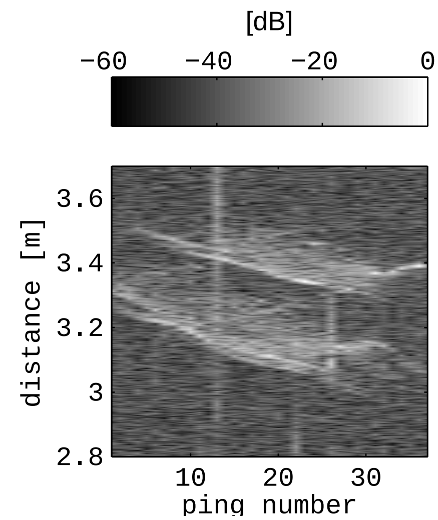

Fig. 3. Range profiles of two mackerels in a school. The mackerel swam in the southeast direction.

Ex-situ experiments were performed in one of the large fish storage aquaria at the North Sea Oceanarium in Hirtshals, Denmark. A total of five hours of data have been recorded in the experiments. Of these, three hours were processed and 131 measurements extracted comprising data from passes of 67 fish of five different species, both single fish and schools of fish. The fish species are cod (*Gadus morhua*), European sea bass (*Dicentrarchus labrax*), gilthead sea bream (*Sparus aurata*), Atlantic horse mackerel (*Trachurus trachurus*), and Atlantic mackerel (*Scomber scombrus*). The lengths of the fish are about 33 to 38 cm for the cods, 25 to 30 cm for the young sea basses, 50 cm for a mature sea bass, 34 to 39 cm for the sea breams, and 35 to 41 cm for the mackerel and horse mackerel. Of the 131 measurements, 82 were without sonar data and 49 with sonar data.

To simplify descriptions below, north means that the fish swims away from the transducer and south that the fish swims towards the transducer. Similarly east means that the fish swims from the left-hand side to the right-hand side of the transducer beam; west means the opposite direction.

The results show range profiles and supporting data for various behaviours of the fish. There are for example, data

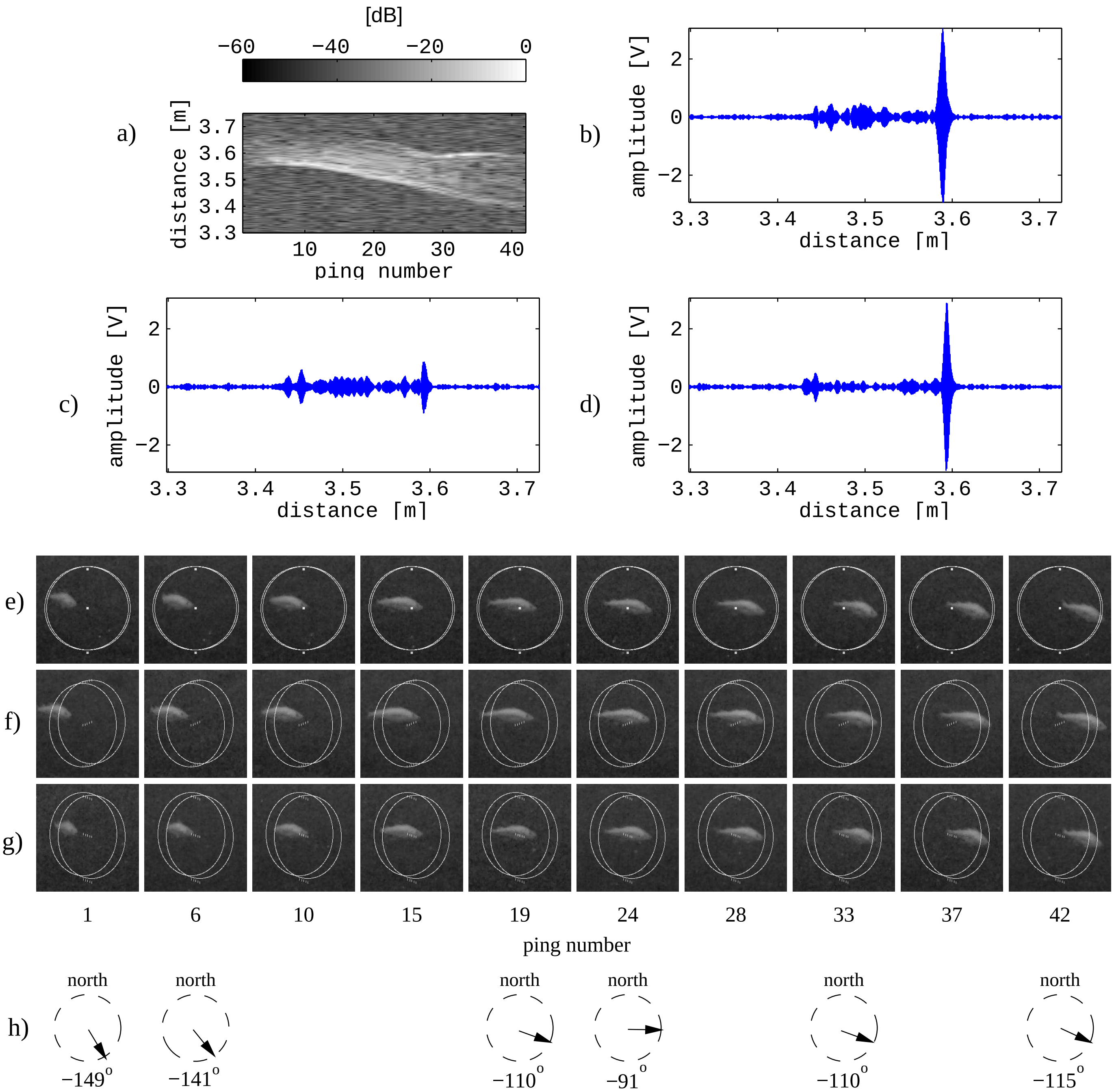

Fig. 4. A cod turned and swam from left to right. Range profiles of the cod (a), RF signal from ping number 31 (b), RF signal from ping number 32 (c), RF signal from ping number 33 (d). Images from the center camera C1 (e), from the left-hand side camera C2 (f), and from the right hand side camera C3 (g). Orientation of the cod for ping number 1, 6, 19, 24, 33, and 42 (h).

from two mackerels in a school, which passed in front of the transducer in the southeast direction (Fig. 3). There is a cod which headed to the transducer from the left, turned towards the east, and then swam in the southeast direction (Fig. 4). There is a school of 4 sea breams which passed in front of the transducer in the southeast direction. In another case, they turned while they were passing the transducer beam, and then swam out in an opposite direction. There are data of a school of mackerel and horse mackerel with a horse mackerel that swam in the southwest direction, turned, and then swam in the southeast direction. There are also data of a school of mackerel and horse mackerel with many complicated movement patterns. Some of the measurements are presented in details in this section.

Range profiles from a measurement on two mackerels are presented in Fig. 3. The fishes swam in a school that passed in front of the Reson transducer in the south east direction. The range profiles present combined echoes from first heads of the fishes, then heads and bodies, whole fishes, bodies and tails and finally only tails. For example, the range profiles at ping numbers 25 to 34 contain echoes of the tail of the nearest of the two mackerels, and profiles at ping numbers 32 to 37 contain echoes of the tail of the second mackerel. The longest profile is about 20 cm and appears when the whole fish is in the beam. This length is likely to be the distance between the head and tail of the fish along the transducer beam. The swimming direction of the fish was southeast as obtained from the video images.

A measurement on a cod is presented in Fig. 4. The cod swam southwards along the center line of the Reson transducer, then turned eastwards, and finally swam out of the beam in the south-east direction. Fig. 4e, f and g present images from the cameras corresponding to a number of specific pings of the Reson transducer. The position of the acoustic transducer beam in the images is shown by circle marks at the minimum and maximum distances axis presented in Fig. 4a. The rectangular marks indicate distances in the center, at the top and bottom of the beam with an interval of 10 cm. Due to the position of the cameras the rectangle and the circle marks in Fig. 4e and g represent larger distances, when positioned more to the right-hand side, while it is opposite in Fig. 4d. An echo from a fish appears only if the fish is within the marks of the acoustic transducer beam for all three cameras. The range profiles of the cod corresponding to 42 continuous pings are presented in Fig. 4a. The lengths of the echo signals from the cod vary as the cod passes by. The maximum length of the echo signals is about 20 cm. From ping number 31 to 35, the echo signals from the tail are much higher than from the other parts (up to 3 times in amplitude) as shown in Fig. 4b, c, and d for ping numbers 31, 32 and 33, respectively. The direction of the body of the cod was the same in all three pings, only the direction of the tail was changed because the cod flicked its tail to swim.

IV. Discussion

In the 10 to 200 kHz frequency range the swimbladder is often considered the most important part of a fish for acoustic fish detection, because reflections from this part is often higher than from other parts. It is more difficult to detect fish of a species without swimbladder because the reflections are significantly weaker [10]–[12]. The work presented here indicates that in the low MHz frequency range surfaces areas of the fish are more important reflectors than the swimbladder, at least from the lateral side of the fish. An example is the measurement on mackerels. Although mackerel have no swimbladder the echoes from them are as strong as those from the other fish species.

When the fish moves, changes in the shape of the surface of the fish, changes in direction that the fish is heading, and the tail flicking generate variations in the range profiles. A simple case to interpret the variations is presented in Fig. 4. The echoes from the tail of the cod are as strong as or stronger than those from the other parts of the body. When the cod had finished turning and headed straight east, the reflections from the tail (ping 30 to 38 at about 3.6m in range) were very high and variable, at ping numbers 31 (Fig. 4b) and 33 (Fig. 4d) up to 3 times stronger than from other parts of the fish. At those pings, the tail was probably very close to perpendicular to the direction of the centerline of the transducer. When the cod flicked its tail the maximum amplitude of the echo signals decreased to about one thirds of the previous value (ping number 32 (Fig. 4c)).

V. Conclusions

In this work, it has been shown that a system consisting of cameras in stereo configuration, a single element transducer and a multi-beam sonar is useful for an initial *ex-situ* study of range profiles from free-swimming fish. Measurements were performed on fish that have swimbladder (cod, sea bass, gilthead sea bream, and horse mackerel) as well as on fish that do not have swimbladder (mackerel). The amplitudes of the backscatter signals from the fish depend strongly on the angle of incidence between the acoustic beam and the surface of the fish. The experiments indicate that at 1MHz the surface areas (also fins and tail) of the fish can give echoes that are much stronger (up to 3 times) than the swimbladder can, therefore important for identification of fish.

Acknowledgment

This work is sponsored by a grant from the Globalization project of the Technical University of Denmark. Special thanks to Henrik Flintegaard and the helpful staff at the NorthSea Oceanarium, Hirtshals, Denmark for very good facilities for the *ex-situ* experiments.

References

[1] W. W. L. Au, B. K. Branstetter, K. J. Benoit-Bird, and R. A. Kastelein, “Acoustic basis for fish prey discrimination by echolocating dolphins and porpoises,” *J. Acoust. Soc. Am.*, vol. 126(1), pp. 460–467, 2009.

[2] J. S. Jaffe and P. L. D. Roberts, “Estimating fish orientation from broadband, limited-angle, multiview, acoustic reflections,” *J. Acoust. Soc. Am.*, vol. 129(2), pp. 670–680, 2011.

[3] Y. Sun, R. Nash, and C. S. Clay, “Acoustic measurements of the anatomy of fish at 220 kHz,” *J. Acoust. Soc. Am.*, vol. 78(5), pp. 1772–1776, 1985.

[4] B. Lundgren and R. N. Nielsen, “A method for the possible species discrimination of juvenile gadoids by broad-bandwidth backscattering spectra vs. angle of incidence,” *ICES Journal of Marine Science*, vol. 65(4), pp. 581–593, 2008.

[5] R. Jørgensen and K. Olsen, “Acoustic target strength of capelin measured by single-target tracking in a controlled cage experiment,” *ICES Journal of Marine Science*, vol. 59, pp. 1081–1085, 2002.

[6] K. Sawada, H. Takahashi, K. Abe, T. Ichii, K. Watanabe, and Y. Takao, “Target-strength, length, and tilt-angle measurements of pacific saury (cololabis saira) and japanese anchovy (engraulis japonicus) using an acoustic-optical system,” *ICES Journal of Marine Science*, vol. 66, pp. 1212–1218, 2009.

[7] M. C. Langkau, H. Balk, M. B. Schmidt, and J. Borcherding, “Can acoustic shadows identify fish species? A novel application of imaging sonar data,” *Fisheries Management and Ecology*, pp. 1–10, 2012.

[8] S. L. Maxwell and N. E. Gove, “Assessing a dual-frequency identification sonars’ fish-counting accuracy, precision, and turbid river range capability,” *J. Acoust. Soc. Am.*, vol. 122(6), pp. 3364–3377, 2007.

[9] S. P. Jacobs and J. A. O’Sullivan, “Automatic target recognition using sequences of high resolution radar range-profiles,” *IEEE Transactions on Aerospace and Electronic Systems*, vol. 36(2), pp. 364–381, 2000.

[10] C. S. Clay and J. K. Horne, “Acoustic models of fish: The atlantic cod (gadus morhua),” *J. Acoust. Soc. Am.*, vol. 96(3), pp. 1661–1668, 1994.

[11] K. G. Foote, “Importance of the swimbladder in acoustic scattering by fish: A comparison of gadoid and mackerel target strengths,” *J. Acoust. Soc. Am.*, vol. 67(6), pp. 2084–2089, 1980.

[12] ——, “Rather-high-frequency sound scattering by swimbladdered fish,” *J. Acoust. Soc. Am.*, vol. 78(2), pp. 688–700, 1985.